

**MATERIALS PROCESSING IN SPACE PROGRAM SUPPORT**

**Final Report**

**Contract No. NAS8-36045**

**Contract Period - April 19, 1985 - March 17, 1987**

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## INTRODUCTION

Materials research in space offers advantages in studying phenomena and preparing materials under conditions which cannot be realized in the gravity field of the earth. An increase in our basic understanding of materials processes will, in the future, enhance our ability to control them more effectively and to adapt them to new and more complex environmental conditions.

Many techniques are being developed to improve processing systems and reduce the effect of these gravitationally induced restrictions. Research opportunities exist using ground-based and unique space-based processing systems. The space-based devices take advantage of a wide range of low-gravity facilities including drop towers and tubes, aircraft and sounding rocket parabolic trajectories, simple materials experiment accommodations in the Space Shuttle, and more complex capabilities in Spacelab. All these systems are being used to not only produce novel materials but also to study materials processing under unique conditions.

The participation of the Universities Space Research Association (USRA) in NASA's Materials Processing in Space (MPS) program began in 1970. The program was designed initially to provide support to the MPS program at the Marshall Space Flight Center (MSFC). The program has continued to provide the organization and administration of colloquiums, science reviews, workshops, technical meetings, bibliographic services, and visiting scientist programs.

USRA's Materials Processing in Space program has two overall objectives. Dr. Martin Glicksman, Rensselaer Polytechnic Institute, directs both the visiting scientist program directly involved with the Marshall Space Flight Center under this contract, and the Discipline Working Groups program managed under separate USRA contract to NASA Headquarters.

In the paragraphs below, we discuss the components of USRA's program in Materials Processing (Microgravity Science) covered under NAS8-36045. The paragraphs are labeled by task, according to the designation in the statement of work. A description of the statement of work is provided in Appendix A.

## Task A

USRA is responsible for the organization and administration of colloquiums, science reviews, workshops and other such meetings in various disciplines of interest to materials processing in space. The purpose of such meetings is to promote interaction between the NASA-sponsored researchers, and those other agencies, universities, and organizations.

A lecture and seminar series was continued to provide a forum for discussion and to stimulate interest in the MPS program. Seminars were presented to MSFC scientists by highly-qualified researchers in the areas of fluid dynamics, numerical modeling, biomedical separation processes, low g experiments in containerless processing and the effects of design, materials, temperature measurements and/or operating procedures on the life of the MEA and AADSL. A complete list of seminars, workshops and colloquiums is included in Appendix B.

A significant aspect of the contract is to support specific areas of research which are of interest to NASA by designated individuals, visiting scientists, and/or small ad hoc groups. With the small ad hoc group approach in mind, the Space Station Advisory Group under the leadership of Dr. Robert Naumann was established, two Commercial Users Workshops were held to explore potential commercial applications of materials processing in space research and a meeting of Fortune 500 companies and NASA representatives was convened to discuss the potential of developing a private industry/NASA partnership in the commercial development of space. USRA also sponsored the participation of eight scientists at the sixth international Congress of Biorheology which focused on experiment requirements for the Space Station. Additional details on ad hoc group meetings are included in Appendix B under the list of seminars, workshops and colloquiums and a list of Space Station Advisory Group members is in Appendix C.

## Task B

An activity which USRA has undertaken in the Materials Processing in Space program has been to maintain an extensive library on material sciences publications.

The preparation of a bibliography on materials processing in space began in 1975 because it became necessary to provide background information on past research in the various disciplines to scientists who were actively

working on current projects in the material sciences. The bibliography was organized from these publications and other additional information and was completed in March 1982. A revision of this bibliography has been published on an annual basis since 1982.

At this time effort is being made to maintain an accurate up-to-date record of all material sciences publications. This is being accomplished by Ms. Elizabeth Pentecost, at USRA/HQ, supported under another contract. Publications are added to the existing library on a continuing basis and are made available upon request to researchers in the field. From these publications, USRA has prepared several bibliographic reports and summaries that tabulated contractual reports and publications in the open literature dealing with the effects of microgravity conditions on materials processing in space. (Materials Processing in Space Bibliography, 1983 Revision, NASA TM-82507, 1983; Microgravity Science and Applications Bibliography, 1984 Revision, NASA TM-86651, 1984); and 1986 Revision, NASA TM-89608.

Numerous scientific papers are submitted and published in the open literature or presented to national and international symposia by the visiting scientists at MSFC. One activity that USRA performed is the preparation of these papers for submission to the science journals. Since these publications must adhere to the editing and style guidelines provided by NASA, it became necessary for USRA to provide the expertise needed by using the services of Ms. Shelby Morris and Ms. Susan Burrer. Ms. Judy Hughes provided these services under the contract to the Space Commercialization Office at MSFC.

#### Task C

USRA convened several meetings to provide technical information in both the basic and applied science aspects of the materials processing program. These meetings are determined jointly by USRA and MSFC. USRA met with MSFC representatives to plan future programs and to give advice on existing programs. It participated in numerous meetings including meetings of advisory committees concerned with experimental facilities for the Shuttle, design and fabrication of flight hardware, organization of the space processing program, experiment requirements for the Space Station and the relationship between NASA and private industry in the commercial development of space.

## Task D

USRA is responsible for providing visiting scientists to advance the Microgravity Science and Applications program. These scientists are recruited from the University community to conduct research in the areas of crystal growth, metals, alloys, and composites; glasses and ceramics; fluid dynamics; protein crystal growth; biotechnology; and mechanics of granular materials.

During the contract period, there have been six USRA visiting scientists undertaking research activities at Marshall Space Flight Center. The following are reports on research activities and results from USRA's Visiting Scientist Team.

### Dr. James M. Van Alstine

In addition to his duties as Deputy Program Director, Dr. James M. Van Alstine pursues an active research program as a USRA Visiting Scientist in the Biophysics Branch of the Microgravity Sciences Division of the NASA/Marshall Space Science Laboratory. Dr. Van Alstine's research interests concerns aqueous polymer two-phase system partitioning of biological material. This process is on the cutting edge of biotechnical downstream processing. The work being carried out at MSFC is directed towards adapting this technology to space bioprocessing, as well as using the unique low gravity environment of space to carry out studies of theoretical and practical importance as regards "partitioning" on Earth. In addition this research impacts on general understanding of the behavior of fluid phase systems in Space.

Over the term of this contract, three space flight experiments were flown (PPE on STS 51D, PSE on STS 51G and PPE-II on Challenger). A reflight of PPE-II is scheduled for STS 26 in July 1988. Approximately 13 papers were published while 9 abstracts and 7 invited colloquia were presented. In addition three patentable inventions were disclosed, one of which (Polymer Coatings To Control Surface Zeta Potential Expression) has been patented by USRA. In addition to numerous invited colloquia, Dr. Van Alstine was invited to speak before the National Commission of Space on the subject of "What Can We Expect From Biomaterials Processing in Space?", and has been awarded two NASA "Certificates of Recognition." For further information please contact Dr. Van Alstine care of this office or at 205-544-7820.

### Ms. Kim Gernert

Ms. Kim Gernert worked on the contract conducting

Protein Crystal Growth (PCG) research. She was a Student Scientific Assistant to Dr. Mary Beth Broom. Working closely with Dr. Daniel Carter, of ES76, Ms. Gernert became an invaluable member of the MSFC PCG Team and contributed towards research papers currently being prepared for journal submission (e.g. A Simple Apparatus for Controlling Nucleation and Size in Protein Crystal Growth by Gernert, K. M., Smith R., Carter, D. C. - to appear in Analytical Chemistry). In the fall of 1987 Ms. Gernert will leave USRA to attend Graduate School at Duke University.

Mr. J. Iwan D. Alexander

Mr. J. Iwan D. Alexander did research in the formulation of a mathematical model of the microgravity field in a spacecraft, including the effects of variable spacecraft attitude and atmospheric drag. Examination of the model's effect on free particle motion and fluid motion.

- analysis of oblique flow onto a growing crystal interface.

- fluid flow in solidifying transparent monotectic systems using two wavelength holography.

- a non-linear analysis of the morphological stability of a solidifying binary alloy, with latent heat effects at the solid-fluid interface.

Dr. Ching-Hua Su

Dr. Ching-Hua Su undertook research activities in the following areas:

Casting of HgCdTe Alloys: HgCdTe melts were solidified under well-defined thermal conditions using a two-zone furnace with heat pipes. The compositional variations along the radial and axial directions were determined by infrared transmission, energy dispersion of X-ray (EDX) and precision density measurements.

Growth of CdS by Physical Vapor Transport: Growth of CdS by vapor transport in a closed ampoule under a thermal gradient was investigated using a horizontal three-zone translation furnace. PbS, PbSe and CdTe were also grown by the vapor growth system.

Growth of HgZnTe Alloys by Directional Solidification: A series of  $\text{Hg}_{1-x}\text{Zn}_x\text{Te}$  crystals were grown by directional solidification with  $x$  ranging from 0.15 to 0.22. The axial and radial compositional variations were determined by precision density measurements, infrared transmission spectra and EDX spectroscopy.

Dr. Mary Beth Broom

As one of the co-investigators on the protein crystal growth project, Dr. Mary Beth Broom was involved in the design, development, and testing of protein crystal growth experiments and hardware for microgravity experiments. Protein crystal growth experiments were successfully flown on four shuttle flights (51-D, 51-F, 61-B, 61-C). Dr. Broom also was involved in the design and testing of "the next generation" of flight hardware for future flight opportunities.

Other research has focussed on the effects of gravitational convection on the morphology of oriented crystals and crystallographic studies on proteins such as human serum albumin.

Mr. George Williams

Mr. George Williams, Visiting Scientist, USRA, worked closely with Teresa Y. Miller, Biophysics Branch, Space Sciences Laboratory. Their research includes evaluating the effectiveness of various microbial contamination control methods including Ultraviolet sterilization, hydrogen peroxide sanitization, and filtration alone for use in a multifiltration water reclamation system. This Multifiltration Waste Water System (MFWWS) was designed, built, and is being tested by a team of scientists and engineers at Marshall. Testing procedures include the use of Millipore techniques for microbial content of samples. The 100 ml samples are collected, filtered, and tested using various types of media specifically designed for identification of coliforms, total bacteria, yeasts, and molds. The results of these tests will be used to compare the performance of the multifiltration system with other technologies available for use in the water reclamation subsystem of the Space Station Environmental Control and Life Support System (ECLSS).

Other research by Mr. Williams included the evaluation of continuous flow electrophoresis systems with Ms. Miller and Dr. Robert Snyder. In particular their research evaluated the cross-section of the sample bands in the plane perpendicular to the electrical flow between electrodes. The research shows that the spread in the direction perpendicular to the migration increased significantly with the applied electric field.

Ms. Judy Hughes

Ms. Judy Hughes also performed an important role in the completion of contract objectives from an administrative position. The Materials Processing in Space Group is in daily contact with people outside the government. One of

Ms. Hughes responsibilities was to compile the names, titles, addresses and telephone numbers of commercial customers, academics and NASA personnel in contact with the program.

In the summer of 1986, she gathered materials for a notebook entitled "Microgravity Science and Applications - Accomplishments, Benefits and Results." This notebook was used to give a presentation to the NASA Administrator as well as other uses such as informing customers of NASA's accomplishments and sending copies to NASA Headquarters.

Ms. Hughes also maintained a User Library. This resource allowed brochures and science documents to be sent to prospective customers, colleges and universities, and anyone interested in Materials Processing.

#### Summary

USRA visiting scientists submitted numerous papers for publication in scientific journals on their work at MSFC. This work spanned a wide range of disciplines, from semiconductor growth to cell separations. These publications were cited in various scientific journals, which indicated how important their work has become to the material sciences community. A complete list of publications in journals and books written by USRA visiting scientists is provided in Appendix D.

#### Financial

Total Estimated Cost of Contract: \$733,115  
Total Cumulative Funds: \$733,115  
% Complete: 100%  
Remaining Funds: 0

The original contract value was \$551,305, however the need for additional research tasks resulted in a modification of \$181,810 on September 11, 1987 to cover the costs associated with these additional tasks.



Appendix A  
STATEMENT OF WORK

The Contractor shall accomplish the following tasks:

Task A

Studies concerning the Materials Processing in Space require analyses in disciplines such as biomedical separation processes; cell separations, proteins, superconductivity; foams; solid state colloids; containerless processes; solid solution semiconductors; vapor transport mechanisms; high purity materials; and fluid dynamics in low-gravity fields, depending upon the problem area. The Contractor will provide, utilizing the large university member institutions, the necessary expertise to solve specific materials processing in space problems with the frequency of need determined by the Technical Contracting Officer's Representative. This expertise can be in the form of colloquiums, science reviews, workshops, and/or discipline specialty people for a 1- or 2-day meeting with in-house materials processing in space personnel.

Task B

Provide the expertise for the bibliography update by searching the materials processing in space literature and adding pertinent items to keep the bibliography current. Areas of interest to the materials processing in space will be identified by the Technical COR Program Scientist and Program Manager. Reference reports will be prepared for distribution to committee members and others as selected by the Program Scientist.

Provide the expertise for the preparation of papers to be submitted to scientific and technical journals and technical reports and presentations to national and international symposia. This scientific documentation shall be prepared in both draft and final product form, utilizing editing and style guides and MSFC guidelines.

#### **Task C**

The dates, location, and participants of necessary meetings will be determined jointly by NASA/MSFC and USRA.

#### **Task D**

Studies in specific Materials Processing in Space disciplines will be defined and requested by the Contracting Officers Representative (COR). The Contractor will independently address these specific disciplines through the use of visiting scientists provided from the scientific community.

## Appendix B

### SEMINARS, WORKSHOPS AND COLLOQUIUMS HELD DURING CONTRACT PERIOD AT MARSHALL SPACE FLIGHT CENTER.

Dr. James Van Alstine, USRA Visiting Scientist at MSFC, participated in debriefing discussions on the phase partitioning experiment aboard Shuttle Mission 51-D, May 21-27, at the Johnson Space Center and NASA Headquarters.

Dr. James Van Alstine, USRA Visiting Scientist at MSFC, participated in a Polymer Workshop in Cleveland, Ohio, May 8-9, 1985.

Dr. James Van Alstine, USRA Visiting Scientist at MSFC, participated in a phase partitioning review held in Vancouver, British Columbia, July 2-4, 1985.

Dr. Iwan Alexander, Carnegie-Mellon University, presented a colloquium on fluid dynamics on July 17, 1985, to the scientists in the Space Science Laboratory.

Two Commercial Users Workshops were held September 25-26, 1985 at NASA Marshall Space Flight Center. The first addressed the AADS-F-Mark I (commercial furnace) and the second workshop addressed the Space Ultra-Vacuum Facility. The workshop was attended by more than 100 participants from university, government, and industry.

Dr. Mary Beth Broom, USRA Visiting Scientist, traveled to NASA Kennedy Space Center July 9-15, 1985, to prepare solutions for Shuttle experiments on protein crystal growth. She again traveled to KSC July 27-29, 1985 to prepare protein crystal growth experiments for the rescheduled Shuttle flight.

Dr. Mary Beth Broom, USRA Visiting Scientist, attended the First International Conference on Protein Crystal Growth August 13-18, 1985 at Stanford University. She co-authored a paper delivered at the conference.

Dr. James Van Alstine, USRA Visiting Scientist, attended the Fourth International Partition Meeting in Lund, Sweden August 18-23, 1985. He discussed his work and mutually authored a book with Swedish partitioners.

Dr. C. W. Chu, University of Houston, was invited as a speaker to the Commercial Users Workshop held September 25-26, 1985 at NASA Marshall Space Flight Center.

Dr. C. H. Su, USRA Visiting Scientist, traveled to the Oak Ridge National Laboratory, Oakridge, TN, September 19-20, 1985. He participated in discussions with Dr. Alan Solomon

and others at ORNL on mathematical models for a MSFC materials science project.

Dr. Iwan Alexander, USRA Visiting Scientist, traveled to Johnson Space Center, October 22-23, 1985, to discuss Space Station science requirements with JSC officials, and his input on fluids.

Dr. James Cronin, University of Delaware, visited MSFC March 25-27, 1986, to discuss possible collaboration on low-g experiments in containerless processing.

The Space Station advisory Group met at the Marshall Space Flight Center April 10-11, 1986. Discussions included reviews of the Teledyne Brown effort to establish requirements for the Space Station Materials Technology Module and the preliminary design efforts of the two Phase B contractors, Boeing and Martin Marietta.

Dr. Milorad Dudukovic, Washington University, presented a seminar at MSFC June 24, 1986, on "Numerical Modeling of Various Microgravity Research Processes."

Dr. Robert Pace, Microgravity Research associates, attended the JSC Space Station Users Working Group meeting, June 16-20, 1986. His presence was needed so the commercial MPS requirements were adequately reflected in the Space Station data management and flow architecture.

Tom Harford, AIAA, convened a meeting of 16 Fortune 500 firms and NASA representatives June 26, 1986, to discuss potential involvement of the companies in the microgravity science program. All the companies that attended were interested in forming a working relationship with NASA in commercial development of space. Several companies involved in previous meetings have signed TEA's with NASA's Commercial Development Office.

USRA sponsored participation by eight scientists at the Sixth International Congress of Biorheology held at the University of British Columbia, Vancouver, July 28-August 1, 1986. The focus of the workshop was experiment requirements for the Space Station. The investigators completed the work they had earlier proposed and pursued new topics in the field of low velocity blood flow with red cell aggregation.

Dr. D. Schaefer and colleagues consulted with Mr. Richard Spann on the effects of design, materials, temperature measurement and/or operating procedures on the life of the MEA and AADSL.

Dean Robert F. Sekerka of Carnegie Mellon University gave a symposium at the Space Science Laboratory on September 23, 1986.

Dr. Iwan Alexander visited the National Bureau of Standards in Washington in November 1986 to discuss an approach to the problem of the effects of glitter on morphological stability with Drs. Conell and McFadden.

Dr. James Van Alstine attended the Director's Meeting (BOG Meeting) at the Lunar Planetary Institute from November 5-8, 1986.

A Space Station Users Working Group Meeting was held on December 4-5, 1986 at Marshall Space Flight Center to discuss space station preliminary design issues.

Dr. Ching Hua Su attended the 1986 fall meeting of the Materials Research Society from November 30 - December 5 in Boston, MA.

Dr. James M. Van Alstine attended as a guest, the 4th International Immunobiology Conference at Las Vegas in December 1986.

Dr. James M. Van Alstine participated in the ESA MPS 6th International Meeting at Bordeaux, France in December 1986. A paper was presented which was published in ESA publication SP-222, 1987. See Appendix D.

July 1987  
Update

Appendix C

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## Appendix D

### PUBLICATIONS BY USRA VISITING SCIENTISTS ON RESEARCH RESULTING FROM ACTIVITIES AT MARSHALL SPACE FLIGHT CENTER,

Alexander, J. I. D., "Oblique Flow onto a Growing Crystal Interface: An Exact Solution," Int. J. Heat & Mass Transf., 1986 (submitted).

Alexander, J. I. D., Wollkind, D. J., and Sekerka. R. R., "The Effect of Latent Heat on Weakly Non-linear Morphological Stability," J. Cryst. Growth, 1986 (in press).

Alexander, J. I. D. and Lundquist, C. A., "Residual Motions Caused by Microgravitational Accelerations," J. Astron. Sci., 1986 (submitted).

Alexander, J. Iwan D. A Weakly Non-Linear Stability Analysis of the Solidification of a Dilute Binary Alloy, with D. J. Wollkind and R. F. Sekerka, J. Crystal Growth, 79, 849-865, 1986.

Alexander, J. Iwan D. Residual Motions Caused by Microgravitational Accelerations, with C. A. Lundquist to be published, Journal of Astronautical Sciences, 1987.

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Alexander, J. Iwan D. On the Orientation of Very Low Frequency Microgravitational Acceleration: Significance for Materials Processing Experiments in Space, manuscript in preparation, with R. Naumann (NASA MSFC), 1987.

Alexander, J. Iwan D. Fluid Flow in the Melt of Solidifying Monotectic Alloys, with A. Ecker and D. O. Frazier, submitted to Metallurgical Transactions A.

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Alexander, J. Iwan D. Microfolding in the Permian Castille Formation - An Example of Geometric Systems In Multi-layer Folding, with A. J. Watkinson, to be submitted to Bull. Geol. Soc. Amer. 1987.

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Herren, B. J., Shafer, S. G., Van Alstine, J. M., Harris, J. M., and Snyder, R. S., "Control of Electroosmosis in Coated Quartz Capillaries," J. Colloid & Interface Sci. 114, (1986).

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Su, C-H, "Heat Capacity, Enthalpy of Mixing and Thermal Conductivity of  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  Pseudobinary Melts," J. Cryst. Growth 78, 51 (1986).

Su, C-H., "Growth Rate of CdS by Vapor Transport in a Closed Ampoule," J. Cryst. Growth, 1986 (submitted).

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## **PAPERS PRESENTED**

**J. Iwan D. Alexander**

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